Dynamics of a Rowing Skiff: Evaluating the Leica GPS 1200 Series

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Abstract

A core challenge in the sport of rowing is determining how the velocity of a skiff actually responds to the power and technique of a chosen crew especially in their training and fine-tuning for races. In general, GPS has been proven to be a viable option in measuring the velocities and accelerations of a rowing skiff under various conditions and equipment options. **However, a key question still remains as to whether current GPS measurement rates are sufficiently rapid to capture the subtle velocity responses of a rowing skiff at a high stroke rate, i.e. approaching forty strokes per minute (spm).** If a skiff's velocity could be determined to sufficient accuracy, then crew selection and coaching would be easier, more accurate and transparent for both coaches and athletes.

This research study used the latest GPS technology from Leica[1] to investigate and evaluate two key questions, namely: (i) to what extent is high-level (20 Hertz (Hz)) GPS a technically viable option for determining the velocity and acceleration of a rowing skiff at race rates (i.e. >36 spm); (ii) when coupled with the latest video coaching software from siliconCOACH, can the GPS-derived positioning provide a state-of-the-art coaching aid.

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[1] The term Leica used herein refers to Leica Geosystems, Heerbrugg, Switzerland

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Introduction[2]

Speed matters. Humans have always sought greater speed whether it is on foot, horseback, or in cars, trains, or planes. This desire to go faster, to increase efficiency and to reduce travel time have also been primary drivers in becoming ever more innovative. The search for such innovation has become increasingly evident in competitive sports such as athletics, yachting, and rowing where the research into improved equipment has been coupled with the ongoing search for better techniques for measuring distance, height and velocity.

Rowing is a premier spectator sport with significant competition at international level, e.g. the modern Olympic Games, and also at national level where, for example, over 400 million people worldwide watch the annual Boat Race between Oxford and Cambridge Universities. The main objective in the sport of rowing is to propel the rowing skiff[3] from a start point to a finish point as fast as possible over a given competition course (typically 2000 metres) with the clear intention of arriving at the finish point before the competition!

Whilst the obvious overall objective is to win the race, the reality is that the actual speed of the skiff can vary quite significantly during the course of the race as the crew apply different techniques and stroke-rates based on their training regime. Consequently, since the introduction of this modern competitive sport, coaches have tried to monitor, analyse, understand, and predict the impact that particular levels of crew effort and movement have on the motion of the skiff itself. Therefore, the principal underlying challenge in rowing is to capture and accurately describe the actual dynamic movement of the skiff through the water.

Competitive rowing is a sport that requires excellent physical conditioning together with high levels of technical skill and mental drive. On the matter of physical preparation, the task of preparing a crew for competition is extremely labour intensive. Moreover, even in 2004, there is considerable uncertainty as to which rowing technique is the most efficient in generating the **highest average velocity** for the skiff.

Of the two key controllable variables, namely the skiff[4] and the crew, coaches have mostly concentrated on preparing the crew. This is because the hull shape has remained relatively unchanged although innovative materials, e.g. carbon fibre, have been used to reduce weight and improve hull stiffness. Consequently, coaches and rowers work endlessly in the belief that, with meticulous preparation, seconds and even fractions of a second can be cut from their competition times. (Churbuck 1988) Certainly, land-based

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[2] A glossary of terms has been included in Appendix B.

[3] The traditional term skiff meant: A flatbottom open boat of shallow draft, having a pointed bow and a square stern and propelled by oars, sail, or motor (Dictionary.com 2002). For the rowing fraternity a skiff is a light, long, narrow racing boat propelled by rowers.

[4] Each individual skiff is tuned (rigged) to suit a specific crew.

tests using rowing ergometers[5] can provide one mechanism for coaches to determine whether a crew **might** be fast on the water. However, the "acid test" is whether the crew **are** fast on the water.

Many techniques for determining velocity are too inaccurate or too cumbersome to determine the skiff's subtle responses to human input. More recently, the development of affordable high accuracy, high update-rate accelerometers has presented one viable option for acceleration measurement on a rowing skiff. However, the data derived from the accelerometers requires expert *a posteriori* evaluation, mainly because the data stream is still uninterruptible by most coaches and athletes (Lin *et al* 2003). Therefore, the core question still remains as to whether the velocity responses are good or bad, big or small, especially at the higher stroke rates provided by a racing crew. If the skiff's velocity can be determined to a sufficiently high level of accuracy, then it would make crew selection and coaching far more effective and efficient. In addition, there are substantial benefits which can be derived by boat manufacturers in testing alternative hull shapes and rigging as part of the overall development process.

The use of GPS as a precision measuring instrument has evolved significantly in the last ten years such that the accuracy and up-date rate is now sufficient to be used for precise dynamic measurements and hence used to determine velocities and accelerations. Recently, GPS has been used extensively on motor vehicles (Milnes and Ford 2001) and supersonic aircraft (Haering 1998). However, the introduction of the Global Positioning System (GPS) into the sport of rowing (see Magee 2002; Lambert & Santerre 2004; Zhang *et al* 2004) has tended to utilize equipment operating at a measurement rate of 10 Hertz (Hz) (or less). There have been few attempts to integrate fully the high accuracy and high update-rate GPS, e.g. Leica 1200[6] operating at 20 Hz, into the overall rowing regime.

By using GPS technology coupled with static and dynamic testing, previous work in the area did demonstrate that GPS can be a viable option for determining the velocity and acceleration of a rowing skiff **under certain conditions.** (Magee 2002) That is, this earlier study used RTK GPS at a 10 Hz data rate, which proved to be successful for a skiff travelling at 20 strokes per minute. As mentioned, the main objective in the sport of rowing is to have the skiff move from start to finish as fast as possible with the clear purpose of arriving at the finish before the competition - twenty strokes per minute will simply not achieve this!

In competition, a top-flight men's eight will be operating at an average stroke rate of 36 per minute with a maximum rate "out of the starting blocks" of up to 55 strokes per minute. At these stroke-rates 10 Hz is unlikely to provide a sufficiently fast epoch rate whereas 20 Hz may provide a solution. Whilst 20 Hz may be a fast enough epoch rate to pick up the subtle changes at rates in excess of 36 spm, important issues then arise from a data management perspective. In fact, more than doubling the amount of data poses some

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[5] A sliding seat and handle connected to a fly wheel with a chain, the rowing ergometer is further explained at (www.concept2.com).

[6] Leica's GX 1230 was used

very interesting challenges regarding data acquisition, processing and analysis. **In effect, rowing presents a very difficult measurement regime.**

The advent of the new Leica System 1200 GPS now presents a real opportunity to confront some of the dynamic measurement problems in rowing for the first time. The use of such high-level equipment tests the feasibility of a 20 Hz testing regime on a rowing skiff at 40 spm with the ultimate goal of being able to use the equipment as a real-time interactive coaching aid.

Synopsis of the Rowing Stroke

An Overview of the Rowing Stroke Characteristics

It takes many years of practice and coaching before an individual will move in proper sychronisation with the rest of his/her crew. It even takes more time before the crew work effectively as a unit. An experienced coach would be looking for the slightest flaw in the crew's stroke, noting every errant splash and check[7], whereas the layperson would see only a long sleek boat surging through the water. (Churbuck 1988)

The typical rowing stroke comprises four distinctive movements: the entry (**catch**) of the blades; the **drive** phase when the blades are being accelerated through the water; the extraction of the blades (**finish**); and the **recovery** phase when the crew moves up the slide[8] (a physically less intensive movement) while preparing for the next stroke. Rowing is a simple sequential repetition of these same movements; catch, drive, finish, recovery. The sequence cannot vary - it can only be improved. (Churbuck 1988)

The objective of a rowing stroke is to accelerate the skiff to maximum speed and then slow it down as little as possible between strokes. (Sayer 1991) The crew that is best able to achieve this process consistently will be the crew that obtains the highest average velocity which generally wins races. Although some variations in speed are inevitable due to crew movements and momentum changes, the effects of the movements can be minimised both through sound technique and the crew's ability to work together as a unit.

Technique and performance has gradually improved as the biomechanics and physiology of rowing are better understood. Thus, it is rare these days to find the extremes of poor body movements once commonly seen in the past, such as the opening of the body at the catch before the leg drive has commenced. (McArthur 1997) Furthermore, the blade entry has become quicker and more effective which maximizes the length and effectiveness of the drive phase. Understandably, because of these typical technical advancements, it has made it increasingly difficult to assess the marginal efficiency of an individual rower's technique and performance and hence their ability to propel the skiff as a crew.

Of interest, the movement of the blade, and the forces applied to it, are not the only factors affecting skiff speed. The crew is much heavier than the skiff and cox, e.g. up to seven times larger for a typical heavyweight crew of eight rowers. As explained by Newtonian's Laws, the movements of the crew up and down the skiff have a large effect on the actual speed. At forty strokes a minute, a crew which rushes into the frontstops[9]

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[7] "Check," the apparent backward movement of a skiff at the catch which is just an increase in the rate of deceleration, i.e. a negative jerk.

[8] Slide: Whereby a seat that moves on wheels up and down two parallel runners 68cm to 81 cm long.

[9] The front of the slide

(catch position) can cause the skiff to check its run. Such checks are highly undesirable and are usually a core component of poor technique. Modern thinking suggests that a controlled unchecked approach will give the highest skiff velocity. (Sayer 1991) However, until recently, it has been almost impossible to quantify accurately the amount of check which different techniques cause in the skiff's velocity.

A Systematic Explanation of the Actual Rowing Stroke

The purpose here is to provide further insight into the generic rowing stroke with catch, drive, finish, and recovery shown diagrammatically with explanation in Figure 1 (overleaf).

The entry of the blade (Catch):
This is one of the hardest parts of the stroke to master because it requires the rowers to be quick and graceful, yet also have an extremely good sense of timing. The blade has to be placed into the water just before the rower meets the front of the slide. This is usually when the rower's shins are in a vertical position. If the blade is placed in the water correctly then an observer located outside of the skiff, or the coxswain, can see a V-shaped splash of water obscuring the blade.

The propulsive phase (Drive):
The drive phase should be initiated by a forceful acceleration of the leg muscles. At this stage the back and abdomen (core) muscles must be engaged in order to provide a strong transmission between legs and the blade. Failure to maintain a braced back will result in the rower "shooting[10] the slide" an action which also causes a reduction in efficient skiff velocity. Once the legs are three-quarters through the drive phase, the body and armdraw commence sequentially until the arms have been completely drawn in. At this point the body is in a relaxed posture at about 5 to 10 degrees from the upright position.

The extraction of the blade (Finish):
The extraction of the blade is then performed by a downward motion of the hands until the blade has cleared the water in its squared position; the blade is then turned to the feathered[11] position. It is essential that this stage of the stroke is done cleanly because a "messy" finish will upset the balance of the skiff which will almost certainly slow it down. The hands should then move away from the body at the same speed as they came into the body.

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[10] Shooting the slide is where the legs are accelerated without the blade, this is usually due to poor back posture, which can be envisaged as a weak transmission in an automobile.

[11] Where the blade is turned to a parallel position with the water.

The movement up the slide (Recovery):
The conventional sequence for the recovery movement of hands, body and slide still holds today. (McArthur 1997) It is crucial that the hands are over the knees before starting to move forward on the slide otherwise the rower will end up in a tangled mess! As in most aspects of rowing technique, the critical requirement through this phase of the rowing stroke is that everyone does the same thing at the same time. Failure to transfer the rower's weight evenly onto the footstretcher at the same time will disrupt the run and the balance of the skiff thereby causing a check in the skiff's velocity.

The speed of the movement towards the frontstops should also be controlled as a crew and, again, should be relative to the speed of the boat. As the rowers approach the frontstops, it is essential that they prepare themselves to change direction without placing too much pressure on the footstretcher before the blade is in the water. This transition is important in order to retain as much of the skiff's momentum as possible. However, as with the catch described earlier, this is one of the most difficult technical aspects to master.

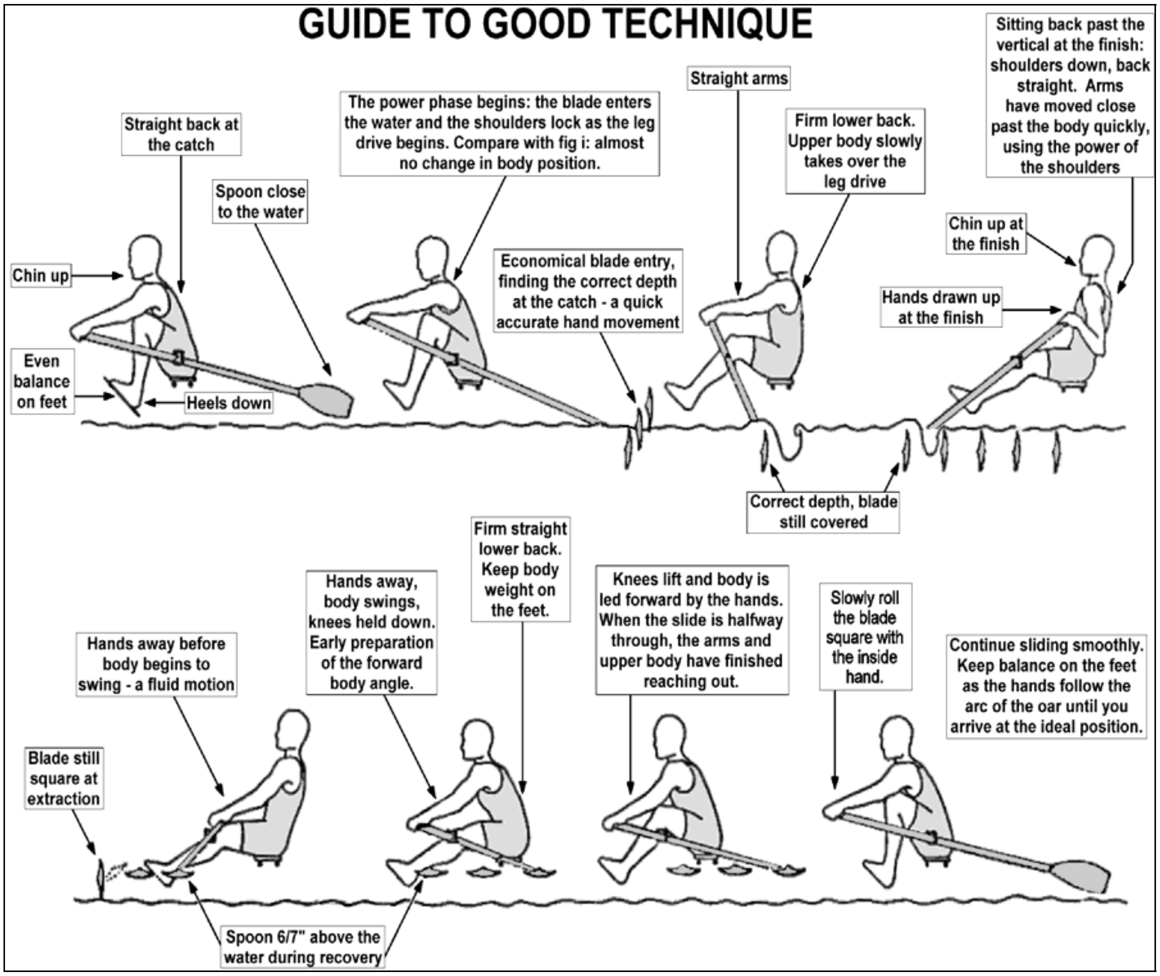

Figure 1: A schematic diagram to good technique (Granger 2002).

The GPS Measuring Equipment

The purpose of this study is to test the viability of high-level GPS for measuring and tracking the changes in the velocity and acceleration of a racing skiff at high stroke rates. Because a skiff undergoes significant velocity changes over small periods of time at high activity, specialised GPS equipment was selected for this study to work, namely the new Leica 1200 GPS.

A significant challenge was always going to be collecting **sufficient** data over the duration of the stroke to enable the corresponding velocities and accelerations to be determined accurately. Martin and Bernfield (1980) successfully collected data from a skiff at 34 to 40 strokes a minute at the required accuracy using a video camera operating at 24 Hz (24 frames per second). Based on this work, it was decided that a receiver capable of a 20 Hz data rate or better would be required. Global Survey was approached with this problem and they suggested utililising the new Leica 1200 GPS because it is a receiver which measures reliably at 20 Hz. The receiver also had the advantage of being housed in a rugged watertight casing which suited the marine environment of rowing.

Another substantive problem lay with the fact that the antenna of the GPS must be located close to the water surface because of the shallow skiff deck. This problem arises because a large body of water is a potential source of considerable multipath error. The new antenna supplied with the system 1200 GPS has a number of technological advances that help mitigate multipath error sources. In addition, the antenna is also waterproof. A number of studies have shown that the new antenna performs as well as the industry standard AT 504 choke ring antenna manufactured by Leica. (Pers.com. Ray Copeland July, 2004)

RTK GPS Positioning Techniques

GPS has been used as a precise measurement tool for over fifteen years now and there is a multiplicity of literature available on the use of GPS for precise positioning. For example: Leick, (1995) deals with the theory of positioning with GPS, and the geodetic foundation for positioning, while Hofmann-Wellenhof *et al* (2001) explain the theory and practice of GPS in depth. At a student level, a brief account of GPS techniques can also be found in Denys (2001, p201-208).

For this research, the Real Time Kinematic (RTK) GPS positioning method was used and, for completeness, this is discussed in more detail. RTK was chosen due to the accuracy requirements and the dynamic nature of this study and also because it is considerably more accurate than the differential GPS positioning technique, which is more commonly used in the marine environment.

Real-Time Kinematic (RTK) requires at least two GPS receivers - a reference receiver plus one or more roving receivers. The reference receiver, otherwise known as the base station, takes measurements from the signals emitted from the satellites available in the field of view at that time. Five or more satellites of the total 24-satellite constellation are required. Generally speaking, the greater the number of satellites the greater the accuracy of the position fix with a need for five or more satellites with a PDOP of 3.0 or better. (Leica 2004).

Degradation of Positioning Precision due to Latency

When significant degradation occurs, latency can be a major source of error in the receiver's precision. Latency is necessary in order for the receiver to measure at 20 Hz. The low latency positioning mode delivers 20 Hz positional fixes at less than 0.03 seconds of latency. (Leica 2004) In the low latency positioning scheme, positional accuracy is traded off for timeliness and it is this degradation of precision that has to be considered in order to assess the viability of the GPS for this particular research task. Any increase in the data link delay relates to an increase in the projection time of the base station phase data and this, in turn, leads to uncertainty in the RTK solution.

To provide a context, a data link latency of 1 second would result in phase projection error approaching 0.02 cycles (0.004 metres). Multiplying the phase projection errors by a PDOP of 3.0 would then yield an increase in error for the low latency RTK solution of 3.0 × 0.004 = 0.012 metres over that of the synchronised RTK solution. (Magee 2002) Precision impacts for this study revolved around whether or not the precision degradation due to latency was going to be a large factor in the "error budget". A latency error may be enough to make the achievable precision of the GPS system at 20 Hz unsuitable for this particular study.

Potential Latency Problems when Synchronising Remote Devices with GPS Positional Data.

Latency becomes even more important when researchers attempt precise synchronisation between the receiver and a remote device such as a video camera. Future development of the analyses described here may require **real time** GPS measurements in order to provide an effective training aid because this would allow a coach to analyse the crew's technique and performance quantitatively and visually. In such circumstances, the problem will lie with quantifying the latency in seconds for a GPS recording rate of 20 Hz, and accounting for it in the remote device to an accuracy of 0.01 seconds or better. In order to obtain accurate synchronisation of a remote device, it would be best to utilize the receiver's PPS output and this means that the latency of the PPS output would also need to be quantified. In practice, the PPS signal has an accuracy of better than 120nano seconds (ns)[12] (3 sigma) therefore creating a latency in the PPS of less than 120ns (Pers.com, Ray Copeland 2004). A latency of 120ns at 20 Hz would be sufficient to synchronise a remote device such as a video camera accurately. Unfortunately, the receiver used in this particular study did not have a PPS output.

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[12] 10^{-9} seconds

SmartTrack AX 1202 Antenna

The SmartTrack antenna has been designed to match the performance of the choke ring antenna while being smaller, lighter (0.44 Kg) and significantly less expensive. The antenna has three distinct features that distinguish it from previous Leica antennas and that also make it more applicable for a dynamic marine environment. First, it has a more precise phase centre. Because the magnitude of the phase centre variations can be in the order of several centimetres this, problem can become significant for applications requiring the highest attainable precision from GPS. (Schubler *et al* 1994) Secondly, the antenna has added features to help minimise the problem of multipathing and, thirdly, the antenna is housed in a watertight casing (submersible to 1 metre for short periods).

In high performance antennas, the variation of the phase centre in the horizontal plane is limited to values of less than 1 millimeter. This variation is regardless of the direction from which the signal is received or the rotation of the antenna. (Krantz *et al* 2002) The SmartTrack is stated to have a submillimetre phase center accuracy. (Leica 2004) A typical example of the GPS antenna phase centre variation resulting from varying elevation angle and azimuth to the satellite appears in Figure 2 below. As shown, the accuracy of the vertical phase centre is of an order three times less precise than the horizontal.

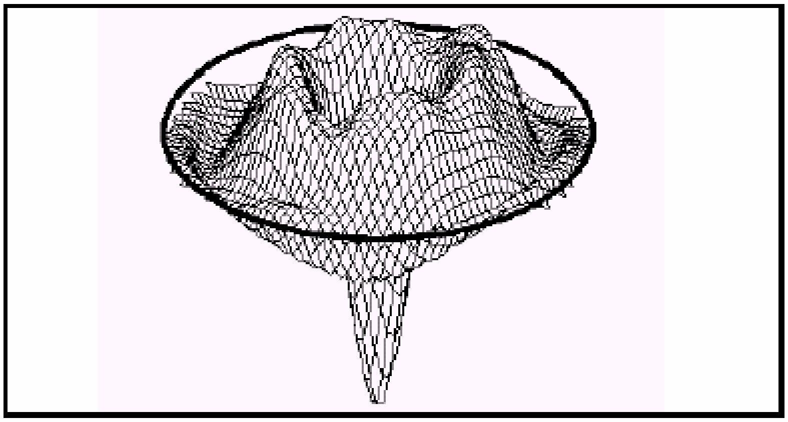

Figure 2: Typical phase centre variation pattern as a function of satellite azimuth and elevation angle (Krantz *et al* 2002).

In effect, the increased accuracy of the phase centre greatly reduces the chance of positional random error thereby increasing the accuracy and precision required for this (and similar) studies. The SmartTracks greatest advancement with respect to this study has been that the new design mitigates much of the multipath effect where multipath introduces errors in the L1 and L2 carrier phase measurements. (Krantz *et al* 2002)

Normally, multipath errors can create significant problems when the antenna is in close proximity to a large body of water. Reflected signals are most likely to be from the sea itself or from the deck of the skiff. In this study, the close proximity of the antenna to the water and the deck of the skiff, namely 10 centimetres above the deck and 40 centimetres

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from the water, means that multipath is likely to be a prominent error source. Because of the difficulty in measuring the error induced by multipathing, especially in a dynamic marine environment, it is helpful to know the equipment being used has some safeguards to cope with this error source. However, it is beyond the scope of this study to determine the exact extent to which a particular antenna mitigates the errors due to multipathing.

Methodology

Skiff Tests

The same methodology was adopted for this testing as was used for an earlier study. (Magee 2002) Two skiff tests were conducted with each one introducing slightly different variables. The first test (1) was conducted on a men's eight operating at **race**, **training** and **start** ratings. The second test (2) was conducted on a men's 1x (single scull) at race ratings. The primary reason for the second test was to try and synchronise video images with the GPS derived velocities. Secondly, a men's 1x travels considerably slower and also has less momentum changes than a men's eight. Consequently, it has been hypothesised that a recording rate of 20 Hz could result in cluttering the data set with unnecessary data. That is, the abundance of data will produce unwanted noise in the velocity and acceleration calculations. (Please refer to Appendix A for further information on the skiff setups.)

Sub-objectives

The sub-objectives of the skiff tests were:

- To test the practicality of the Leica 1200 GPS measuring at 20 Hz when used to assess the velocity and acceleration changes of a men's eight at race and training rating.
- To test the viability of the Leica 1200 GPS on a men's 1x which is slower and has less momentum changes.
- To try and synchronize video images with the GPS data albeit in an experimental mode.

The purpose and scope of the study was described to the oarsmen, coxswain, and coach on the day before the study took place. An immediate problem to be overcome was attaching the antenna to the stern deck of the skiffs. This was overcome by making a polystyrene bracket which was reinforced with a brass base plate screwed over a 5/8" thread. The base plate also helped hold the 5/8" thread in place as appears in Figure 3. The bracket itself was fixed to the deck using high quality 3M insulation tape.

Figure 3: The polystyrene bracket used for mounting the GPS antenna and TPS 360^0 prism on the skiffs. The skiff shown is the Men's 1x

Test One: Men's Eight Tests.

Test one was conducted on 01/08/2004 in Dunedin Harbour in an area adjacent to the Otago University Rowing Club (OURC) facilities. The physical testing conditions included: a slight breeze; an outgoing tidal current; and, an overcast sky with intermittent showers. The testing occurred during the crew's normal Sunday morning training period which is between 8:00am and 10:00am.

Figure 4: The location of the antenna on the stern of the men's eight.

The receiver was configured to measure at 20 Hz in auto mode. The coxswain was then shown: how to change the point codes; how to start and stop the receiver recordings; and how the receiver indicates to the user if the solution is of fixed or float precision. The coxswain comprehended the functionality of the controller without any problems. (Figure 4 shows the locality of the antenna during the eight trial.)

The receiver was initialised on shore to ensure the system was working correctly before the crew took to the water. The crew and coxswain were also reminded about the necessary requirements for the tests to be successful, i.e. that for the first test (1A), it must be conducted from a standing start and the skiff's stroke rate was to remain at thirty-eight and above for the duration of the test. The second test (1B) was started from a rolling start where the base rate was at 20 spm and the crew was then instructed to increase the rate incrementally until a rate of 42 spm was reached. (Figure 5 shows the crew at 20 spm before the start of test 1B.)

Figure 5: The crew at 20 spm before test 1B.

The crew was also instructed to decrease the rate from 42 spm once that was achieved until a base rate of 18 was reached. The third and final test (1C) required the crew to row square blade from a rolling start at a rate of 18-20 strokes per minute. Test (1A) was conducted with a slight head breeze blowing with the second (1B) undertaken in tailwind conditions. The third and final test (1C) was carried out in cross-wind conditions. The tide was ebbing throughout all three tests.

Once the rowers began, the coxswain started data recording to the receiver. The controller was then placed on the coxswain's lap so he could carry on with his normal job.

Test Two: Men's Single Scull Test.

The second test was conducted about a week later on 09/08/2004. The test site and equipment configuration were identical to test one with the test conditions including a stiff southerly breeze, a sizeable chop, and an out-going tidal current. Consequently, the weather conditions meant that only two hundred metres of water was available for testing. This set of tests was labeled with a different code in the data controller.

The main purpose for this set was to test whether it is possible to synchronise video images with the GPS data. A digital video camera was located on the bank approximately 20 metres at right-angles from the course. Each test was started from a static start with the rating kept above 38 spm for the duration of the two hundred metres. Test one (2A) and two (2B) were rowed into a head-and-cross wind and the third test (2C) was completed in tail-wind conditions with all three tests conducted during an ebb tide.

In order to synchronise the video images with the GPS data, the oarsman dropped his hand on the rigger at the same instant that he started the GPS recording. The film crew zoomed-in so that the drop of the hand on the rigger could be accurately recorded (the rigger is the white triangular apparatus attached to the yellow hull in Figure 6.) (Figure 6 shows the equipment set up as tested on the 1x, all the receiver and radio equipment are stowed below the footboard.)

Figure 6: The set up as tested on the water in the 1x trial.

Analysis

The receiver files were imported into Leica Geo Office (LGO) where the data was transformed into a more usable format by converting the receiver's WGS 84 latitude and longitude coordinates into New Zealand Map Grid (NZMG) easting and northing coordinates. The positional data was imported into Microsoft Excel 2000 as a comma delimited file directly from the raw text file created by LGO. The time stamps were converted in Excel from hours minutes and seconds, to seconds.

Once the positional data and time stamps had been imported into Excel, the velocities and accelerations of the skiff were calculated using the following equations:

The skiff's velocity between points (E_1 N_1), (E_2 N_2), and (E_3 N_3).

$$v_{12} = \frac{\sqrt{(E_2 - E_1)^2 + (N_2 - N_1)^2}}{(t_2 - t_1)}$$

which can be expressed as

$$\begin{aligned} v_{12} &= ((E_2 - E_1)^2 + (N_2 - N_1)^2)^{\frac{1}{2}} (t_2 - t_1)^{-1} \\ &= ((E_2 - E_1)^2 + (N_2 - N_1)^2)^{\frac{1}{2}} \Delta\, t^{-1} \end{aligned}$$

Equation 1.1

Similarly, the skiff's acceleration can be expressed as (Equation 1.2).

$$a_{12} = \frac{(v_{23} - v_{12})}{(t_2 - t_1)}$$

or

$$\begin{aligned} a_{12} &= (v_{23} - v_{12}).(t_2 - t_1)^{-1} \\ &= (v_{23} - v_{12}).\Delta\, t^{-1} \end{aligned}$$

and can be expanded in terms of the horizontal position ordinates, namely:

$$a_{12} =: \left\{ \left[(E_3 - E_2)^2 + (N_3 - N_2)^2\right]^{\frac{1}{2}} - \left[(E_2 - E_1)^2 + (N_2 - N_1)^2\right]^{\frac{1}{2}} \right\} .\Delta\, t^{-2}$$

Equation 1.2

Results

The overall intention of the first test was to evaluate the viability of a 20 Hz capable GPS to determine accurately the velocity and acceleration of a men's eight at race stroke rates. Figure 7 shows the velocity and acceleration of the skiff at 40 strokes per minute (spm), during test number 1A. (Note: Because the acceleration is a derivative of the velocity, it is much noisier than the velocity when it is portrayed diagrammatically.)

Results: Men's 8 Oared

Explanation of the Graphs in Terms of the Rowing Stroke

Reference to Figure 7 will be made using a time scale in seconds along the (x axis) of the graph. The appearance of velocity time graphs in this study are consistent with a number of other studies including Williams and Scott (1967); Martin and Bernfield (1980); Magee (2002); and Zhang (2004).

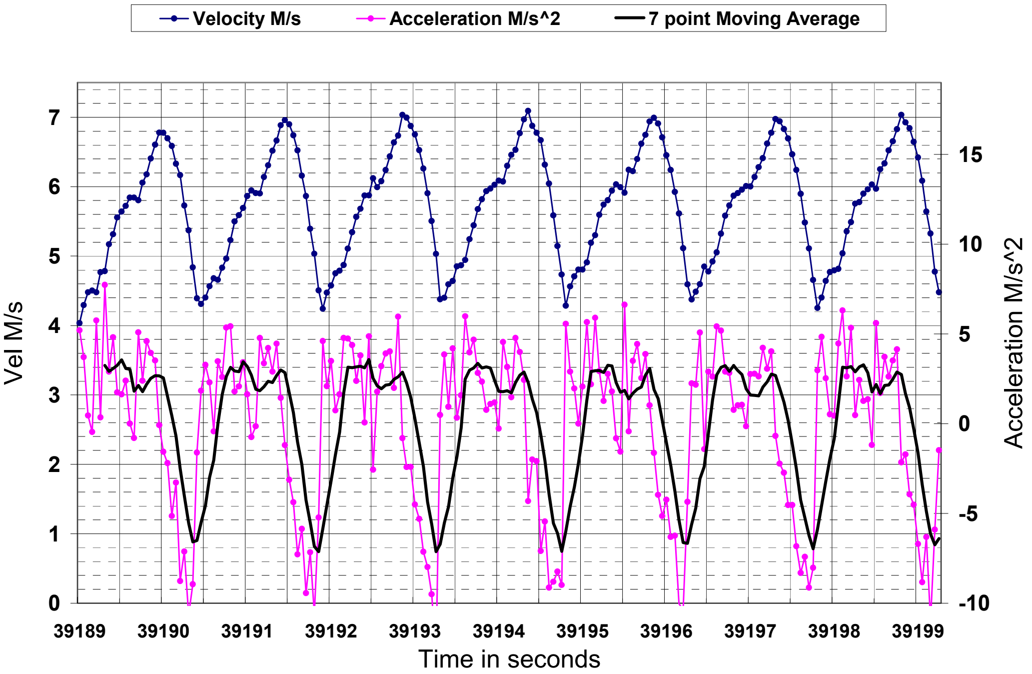

Figure 7: Graph of velocity and acceleration test (1A) rate 40 spm.
Velocity (blue line, left hand axis) and acceleration (pink line, right hand axis). The velocity and acceleration plots have been overlaid with a 3-point moving average (black line).

At point 39190.2, a fraction after the apex of the velocity graph, the catch sequence of the stroke begins and the crew then starts the drive phase. Between 39190.6 – 39190.8, the crew has now reached the lowest velocity with this occurring approximately 30% through the leg drive. This is due to the time it takes the crew to change their momentum relative to the skiff and by the delay-time it takes to generate enough force to overcome the resistant forces acting on the skiff. (Martin and Bernfield 1980) The blades also have to be accelerated to a speed that is faster than the skiff itself before any sort of effective acceleration will occur. (Martin and Bernfield 1980)

At 39191 the crew is now in the most powerful section of the drive phase and with about one-quarter of the slide to go. It is also important to note the check in the velocity at point 39191 and it is clear that this check remains very consistent throughout all of the strokes shown. It is at this time that the crew's bodies begin to accelerate towards the bow. At point 39191.3 the crew are all in the finish position and they begin to release the blades. Again, one should note the consistent check where this check is likely to be caused by some or even all of the oarsmen physically hitting their bodies with the handle of the blade and also by the extraction of the blade from the water.

Readers should note that most if not all of the aforementioned checks are defined by just three points on the graph (velocities) and, therefore, it is a reasonable assumption that an instrument with a data rate of less than 20 Hz would be unable to pick up these subtle movements.

At point 39191.6 the crew begin the recovery phase. At this point the velocity begins to accelerate steadily before the crew take the next catch. The momentum of the crew (crew 75 Kg x 8 = 600 Kg) causes a large acceleration in the skiff (skiff 95 Kg + cox 55 Kg = 150 Kg). The acceleration is caused by the differences in these masses where, instead of the crew pulling themselves towards the frontstops, the crew actually pull the skiff beneath them thereby accelerating it. The force the crew administers to slow themselves down before they change direction at the frontstops has an adverse effect on the skiff and slows it down (39191.5). At point 39191.8 the catch sequence begins again.

Figure 8 shows the crew rowing with a square blade at approximately 20 spm during test (1C). It shows that velocity curve is less abrupt at the lower speeds than when the crew is at race rates, i.e. >36 spm. Further, the second check which occurred in the previous test (1A), when the crew drops the blades out is almost non-existent here.

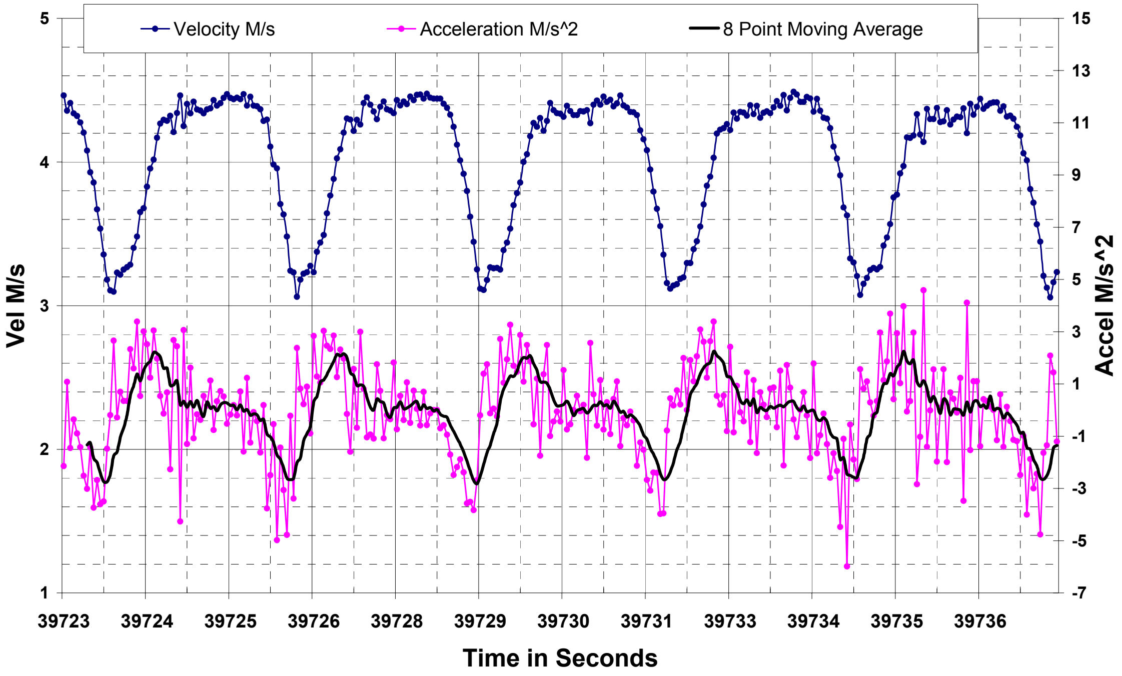

Figure 8: Graph of velocity and acceleration test (1C) rate 20 spm.
Velocity (blue line, left hand axis) and acceleration (pink line, right hand axis). The velocity and acceleration plots have been overlaid with an 8-point moving average (black line).

Figure 8 appears to have a lot of random noise through the velocity curve especially during the recovery phase of the stroke. However, it is explained (Sensitivity Analysis Pg 25) that this error may be due to a positioning error in the system. For example, a one-centimeter positioning error at this ordinate can produce an error of -0.26 m/s in the velocity and this value can actually be seen in Figure 8. Similarly, a one-centimeter positioning error can result in an error of +5.3 m/s^2 in the acceleration component. This too is confirmed in Figure 8 (right hand scale) where the noise in the acceleration curve is up to ±4-5 m/s^2.

Figure 9 is derived from test (2B) where, as the diagram shows, the crew was steadily increasing their rating and velocity. Of interest, it is actually humanly impossible for a crew to create such large accelerations over such a short period of time. (Pers.com Stephen Stanley 2004) One should also note that the random positional error becomes less apparent as the skiff's velocity steadily increases.

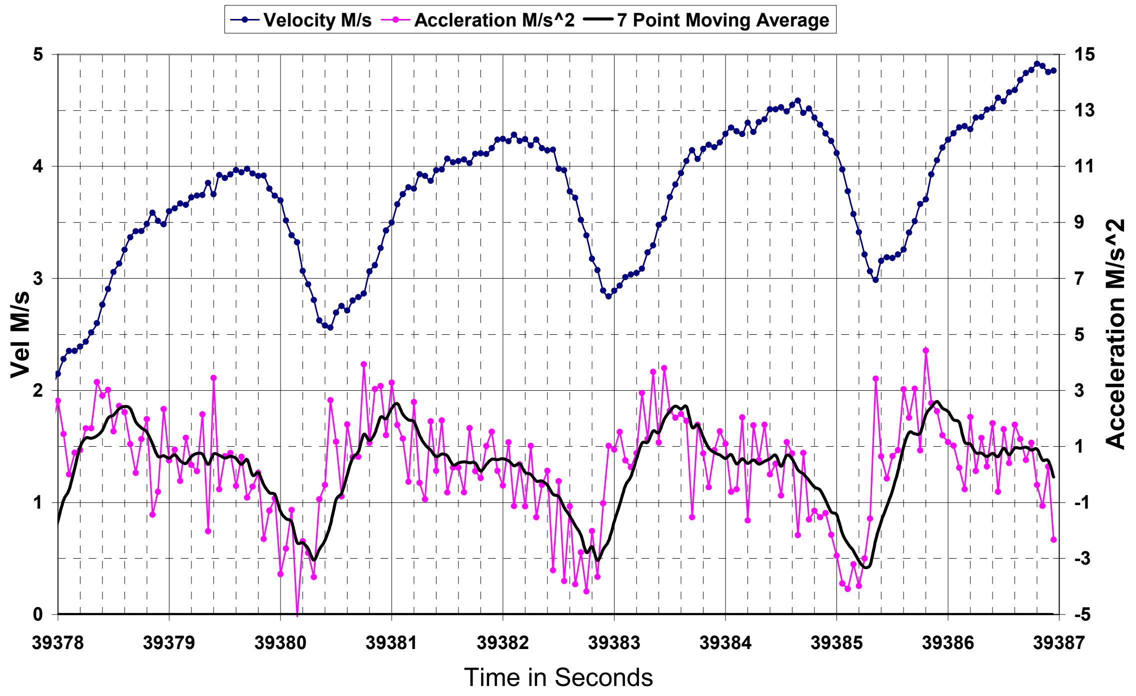

Figure 9: Graph of velocity and acceleration test (2B) 20 + spm.
Velocity (blue line, left hand axis) and acceleration (pink line, right hand axis). The velocity and acceleration plots have been overlaid with a 7-point moving average (black line).

Results: Men's 1x

The same analysis techniques were used here as described in the previous men's eight tests above.

Figure 10 overleaf shows the velocity and acceleration of the 1x at 38-40 spm when measured at 20 Hz test (2A). One noticeable difference between Figure 7 and Figure 9 lies with the quantified values for the velocity and acceleration respectively and this is simply because the 1x is traveling slower than that of the eight. The two checks that were seen during the tests on the eight-oared skiff are again salient features of the single scull's velocity. However, the checks are clearly larger throughout the 1x velocity graph. An explanation for this could lie with the relative mass differences between crew and skiff. That is, an eight-oared skiff weighs 25% of the total systems mass where the single weighs just 16% of the system weight. Thus, the single crew will have a greater influence on the boat's velocity. This can be seen in Figure 10 at 45450.4 seconds. At 45446 seconds in Figure 10 a third check in the velocity can be seen. Because this velocity data has actually been synchronised with video data, a visual appraisal could be made of the technical fault which is causing the third check. The third check appears to be caused by the blade hitting the water during the recovery phase.

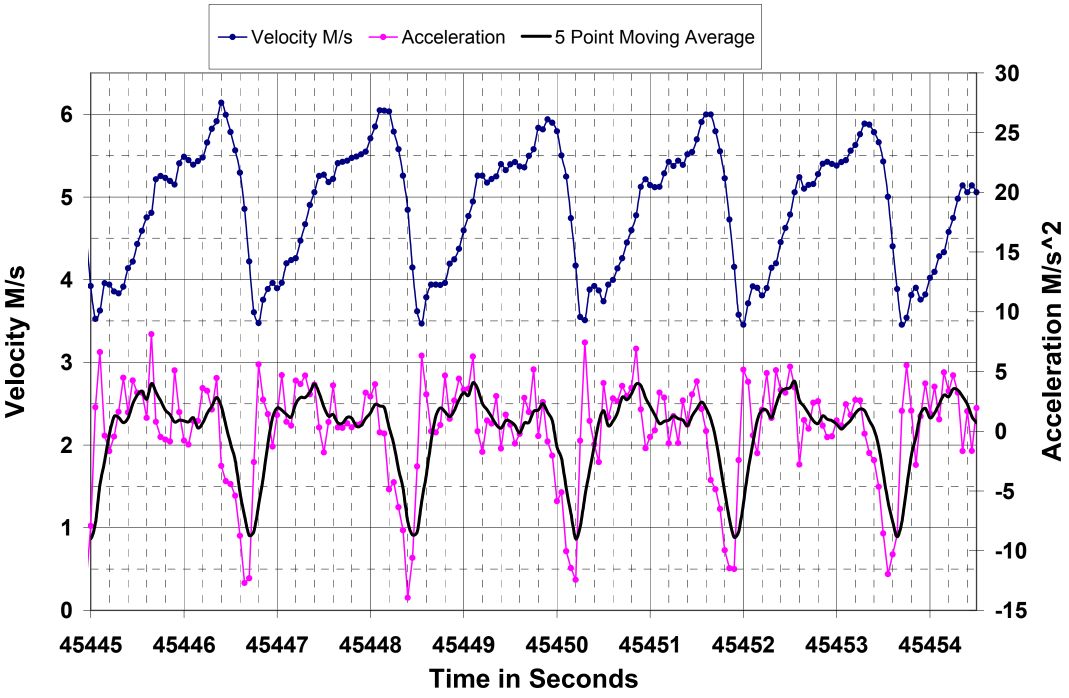

Figure 10: Velocity and acceleration 1x test (2A) 38-40 spm.

Velocity (blue line, left hand axis) and acceleration (pink line, right hand axis). The velocity and acceleration plots have been overlaid with a 5-point moving average (black line).

This study has shown that a 20 Hz update is needed to determine accurately the velocity of a rowing skiff at race rating of 38-40 spm. Any instability in the balance of the skiff is not visually apparent in the velocity curves between the respective data sets, eight-oared, or 1x solutions.

Skiff imbalance can cause 0.5 m of horizontal movement in a men's eight on a rough day. Remembering that the antenna is 0.5 metres from the water, coupled with 30^0 of expected imbalance either side of the vertical, basic trigonometry suggests that the antenna should experience 0.5 metres of movement. Magee (2002) found that the GPS equipment is accurate enough to pick up the balance characteristics of a skiff. However, Magee (2002) suggests that the balance does not seem to affect the velocity or acceleration calculations.

Conclusion

The two skiff tests were conducted to test the viability of high-level GPS as a tool for picking up the velocity and acceleration of a skiff at race rate. Due to the subtle but quick velocity changes, this study demonstrated that a 20 Hz update rate is needed for a skiff traveling at race ratings. The results obtained were consistent with those published elsewhere, notably, Martin and Bernfield (1980); Magee (2002); Zhang (2004). It must be noted that the most useful data from a rowing skiff comes from the skiff at race speed with a stroke rate in excess of 36 strokes a minute, this has now been successfully achieved.

Sensitivity Analysis

No measurement is ever exact. As a corollary, every measurement contains error. These statements are fundamental and universally accepted. (Wolf and Ghilani 1997) GPS measurements are no exception to these rule-statements.

GPS determined positions are used to obtain detailed velocity and acceleration changes over small increments in time. Therefore, it is important to determine the precision and/or accuracy of the positions as actually determined. If the GPS positions are only accurate to 5cm, then this will obviously limit the accuracy to which the velocity and acceleration can be determined especially over short time intervals. Clearly, if the GPS positions are accurate to 0.5cm, then the ability to resolve velocity and acceleration improves considerably.

Leica have stated that the 1200 receiver readily achieves a one-sigma precision of one centimeter plus one part per million. The precision degradation in the position fixes between static and dynamic data will are assumed to be negligible (Magee 2002).

In this section standard sensitivity analysis techniques have been used. Saltelli *et al* (2000) and Denys (2001) describe the differential analysis technique employed in this study.

The sensitivity analysis investigates how errors in position and time propagate into the derived velocities and accelerations of the skiff. This will quantify the level to which the velocity and acceleration can be determined at any one point in time.

Note: this section only indicates how a 1 centimeter error in the GPS determined position may adversely affect the level of precision to which the velocity and acceleration can be calculated. The section does not indicate the actual errors in the velocity and acceleration, seeing the errors are random, the errors in the velocity or acceleration may be better or worse than those values indicated in this section.

Errors in the System

Errors can be characterized into three different groupings, namely; random, systematic, and gross errors or blunders. Random errors are characterised as errors owing to the normal measurement process and can be quantified by estimating the measurement variance (σ^2) or standard error (σ). In general they are a result of human and instrument imperfections. They are generally small and are as likely to be negative as they are positive. (Wolf and Ghilani 1997)

Systematic errors may be due to the measurement process (for example an uncalibrated piece of equipment) or an effect that has not been taken into account (for example the phase centre of the GPS antenna). Throughout this study systematic errors have been notated as Δ.

For this sensitivity analysis, a nominal value of one centimetre has been used as the *a priori* error for each component of the coordinated points (either ΔE or ΔN). This value was derived from Leicas's stated accuracy, as mentioned before.

Because only one oscillator (clock) is used to time stamp the position data from the receiver, the time stamps stated in the data string are highly correlated. Since the oscillator's correlation is unknown, the receiver's oscillator could be treated as a systematic error (Δ).

Systematic Error Sensitivity Analysis

It is of interest to determine the effect of specified systematic errors in the variables used to calculate the velocity and acceleration of the skiff using Equations 1.1 and 1.2 respectively.

There are seven systematic error components when deriving the skiff's velocity and acceleration (i.e., Δv, and Δa respectively). These components are related to the errors in the skiff's GPS determined position; namely the errors in the easting and northing coordinates at points one, two, and three, along with an error in the oscillator's time stamp. These seven error components are shown in Equation 2.1.

$$\Delta\mathbf{x} = \begin{bmatrix} \Delta E_1 \\ \Delta E_2 \\ \Delta E_3 \\ \Delta N_1 \\ \Delta N_2 \\ \Delta N_3 \\ \Delta(\Delta)t \end{bmatrix} \qquad \text{Equation 2.1}$$

The effect on the resultant skiff's velocity (Δv) and acceleration (Δa) is given by:

$$\begin{bmatrix} \Delta v \\ \Delta a \end{bmatrix} = \mathbf{J}_{E,N}\Delta\mathbf{x}$$

where, $\mathbf{J}_{E,N}$ is the Jacobian matrix.

$$\mathbf{J}_{EN} = \begin{bmatrix} \frac{\delta v_{12}}{\delta E_1} & \frac{\delta v_{12}}{\delta E_2} & \frac{\delta v_{12}}{\delta E_3} & \frac{\delta v_{12}}{\delta N_1} & \frac{\delta v_{12}}{\delta N_2} & \frac{\delta v_{12}}{\delta N_3} & \frac{\delta v_{12}}{\delta \Delta t} \\ \frac{\delta a_{12}}{\delta E_1} & \frac{\delta a_{12}}{\delta E_2} & \frac{\delta a_{12}}{\delta E_3} & \frac{\delta a_{12}}{\delta N_1} & \frac{\delta a_{12}}{\delta N_2} & \frac{\delta a_{12}}{\delta N_3} & \frac{\delta a_{12}}{\delta \Delta t} \end{bmatrix} \qquad \text{Equation 2.1}$$

Using nominal values and assumed systematic errors *a priori* for a specific position at a specific epoch, it is possible to determine which variables have the most significant effect on the calculated velocity and acceleration. The results of the systematic errors in the skiff's position (easting and northing), at points one, two, and three, along with the estimated oscillator error are illustrated in Tables 1.1 - 1.4.

To determine the effect of a single error component, e.g., ΔE_1, the nominal error value of 0.01 metre is given to this component and all other error components, e.g., ΔE_2, ΔE_3, ΔN_1, ΔN_2, ΔN_3, and $\Delta(\Delta)t$, remain errorless. The reason for this is because the interactions of the errors are complex and unknown. The idea of the tables is to show the effects that such an error in the position, e.g., ΔE_1, or time $\Delta(\Delta)t$, may have on the determined velocity and acceleration of the skiff.

The values used for the velocity and acceleration throughout the error analysis have been taken from the computed velocity and accelerations Figure 7 (men's eight test (1A)). For example, in Table 1.1 where the velocity and acceleration stated is 6.26m/s, and 3.01m/s^2 respectively. These values are characteristic of the skiff when it is in the recovery phase at 40 spm. During the drive phase values of 4.89 m/s and 3.15 m/s^2 have been used. This reflects the highly dynamic nature of a skiff, which is a period of reasonably constant acceleration followed by a short deceleration then acceleration.

Tables 1.1 and 1.2 shows the corresponding effects on the skiff's velocity and acceleration respectively during the recovery phase at 40 spm.

	Systematic Error			
Effect	($\Delta E1$, $\Delta N1$)	($\Delta E2$, $\Delta N2$)	($\Delta E3$, $\Delta N3$)	$\Delta(\Delta)T$
(m/s)	(0.01,0.01) (m)	(0.01,0.01) (m)	(0.01,0.01) (m)	$1.0\text{x}10^{-9}$ (sec)
Δv	0.26			
		-0.26		
			-0.28	
				$-1.2\text{x}10^{-7}$

Table 1.1: The effects of systematic errors on the velocity calculation. Recovery Phase – velocity = 6.26m/s, acceleration = 3.01m/s^2

During the recovery phase Table 1.1 it is assumed that the GPS computed position has an error of one centimetre 0.01 m in both the easting and northing coordinates at position one. The propagation of systematic errors will result in an error in the velocity of 0.26 m/s. However, it should be noted that these effects on the skiff's dynamics can either compound or cancel each other out. This is dependant upon the errors in the system at a specific position in this case at either points one, two, three, or the clock error. For example Table 1.1, if a one centimetre error in the eastings and northings was consistent at both point one and two the effects on the skiff's velocity would be cancelled (i.e., 0.26 + -0.26 = 0.00 m/s). However, the same systematic error of 0.01 m in both positions two and three will result in the error in the velocity to compound -0.54 m/s.

Effect (m/s^2)	Systematic Error (ΔE1, ΔN1) (0.01,0.01) (m)	 (ΔE2, ΔN2) (0.01,0.01) (m)	 (ΔE3, ΔN3) (0.01,0.01) (m)	 Δ (Δ)T $1.0x10^{-9}$ (sec)
Δa	-5.22			
		10.43		
			-5.31	
				$1.8x10^{-7}$

Table 1.2: The effects of systematic errors on the acceleration calculation. Recovery Phase – velocity = 6.26m/s, acceleration = $3.01m/s^2$

Effect (m/s)	Systematic Error (ΔE1, ΔN1) (0.01,0.01) (m)	 (ΔE2, ΔN2) (0.01,0.01) (m)	 (ΔE3, ΔN3) (0.01,0.01) (m)	 Δ (Δ)T $1.0x10^{-9}$ (sec)
Δv	0.27			
		-0.27		
			-0.26	
				$-9.7x10^{-8}$

Table 1.3: The effects of systematic errors on the velocity calculation. Drive Phase – velocity = 4.89m/s, acceleration = $3.15m/s^2$

Similarly, errors in the positioning through the drive phase Tables 1.3 - 1.4 have approximately the same effects on the velocity as the errors in the recovery phase Tables 1.1 - 1.2. In a collective sense the error values in the velocity and acceleration between the recovery phase and drive phase have a similar magnitude. This is possibly due to the skiff's relatively consistent acceleration and velocity. Magee (2002) also noticed a consistent magnitude for the errors in the determined velocity and acceleration between the drive and recovery phases for a men's eight traveling at 20 spm.

Effect (m/s^2)	Systematic Error (ΔE1, ΔN1) (0.01,0.01) (m)	 (ΔE2, ΔN2) (0.01,0.01) (m)	 (ΔE3, ΔN3) (0.01,0.01) (m)	 Δ (Δ)T $1.0x10^{-9}$ (Sec)
Δa	-5.31			
		10.62		
			-5.26	
				$1.3x10^{-8}$

Table 1.4: The effects of systematic errors on the acceleration calculation. Drive Phase – velocity = 4.89m/s, acceleration = $3.15m/s^2$

As mentioned previously this section only describes the errors that **may** occur in the velocity and acceleration if a 1 centimeter positioning error occurs. However, if a 1 millimeter error was to occur in every ordinate at positions one, two, and three, this would equate to an error in the velocity of 0.03m/s and an error in the acceleration of 0.01m/s^2. Therefore, it is impossible to determine the error in the velocity and acceleration unless each GPS error can be accurately determined at each position.

The errors in the acceleration at position two Tables 1.2 and 1.4 is approximately twice the magnitude of the errors in the accelerations at positions one and three. This is because the coordinates of position two are used to calculate the acceleration between points one and two, and between points two and three.

Conclusion of Systematic Error Sensitivity Analysis

It is clear from the analysis there are no significant differences in the effects between the velocity and acceleration among the recovery and drive phases at 40 spm. This means the errors have no extra influence on the determination of the velocity or acceleration of the skiff regardless of the skiff's phase e.g. drive, or recovery. As mentioned earlier, the error analysis only gives a guide on the errors that could be in the system.

siliconCOACH

As mentioned previously in this report, siliconCOACH was approached to help with the problem of amalgamating video data with GPS derived velocities. At present, siliconCOACH Ltd. produces motion analysis software for people interested in analysing motion, enhancing performance and reducing the risk of injury. siliconCOACH Pro is the company's premier video analysis software. It is designed for the sports coach, athlete, sport scientist, podiatrist, teacher, chiropractor, or physiotherapist. It also has many major advantages over normal video. For example, the user can split a movie frame into two fields. This allows one to view 50 PAL/60 NTSC images per each second of original digital video which is essential in order to analyse fast or complex movements accurately. (siliconCOACH 2004)

siliconCOACH have already completed some work with New Zealand rowing where the coaches were interested in measuring the sequencing of events (catch, finish etc), for members of a rowing squad during on-water rowing. In siliconCOACH Pro's Manual mode they were able to set the clock and advance the video frame by frame to identify the timing of the various phases of the rowing stroke. These times were then transferred to an Excel report template and graphed. They were also able to measure knee angles using siliconCOACH Pro's Angle measuring tool.

Using this analysis, they were able to provide rapid feedback to the rowers. The video feedback also assisted in identifying which rowers were ahead or behind other team members in various phases of the rowing stroke and allowed them to improve their synchronization as a crew (siliconCOACH 2004).

This study used a similar approach in that the video images were captured from the harbour bank and later fed in to the computer. The GPS data was captured as explained in the previous sections. The GPS velocity data was placed into EXCEL before being placed into siliconCoach Pro. As mentioned above, the video images are split into two sets of images which effectively produces 50 Hz worth of video data. However, this needs to be amalgamated with the 20 Hz of GPS data. Fortunately, the software has a function whereby it will amalgamate the 20 Hz data with the closest video frame in terms of time.

The results were rewarding and a number of screenshots from siliconCOACH can be seen individually below listed as Figures 12-15. Figure 12 shows the oarsmen just after the catch at the start of the drive phase while Figure 13 shows the oarsmen at a point approximately 30 % through the drive phase. Figure 14 shows the oarsmen near the end of the drive phase just before the oarsmen extract the blades from the water. Finally, Figure 15 demonstrates shows the single rower three-quarters through the recovery phase before the catch. Even a non-rower can see that the data is likely to be extremely useful for coaching.

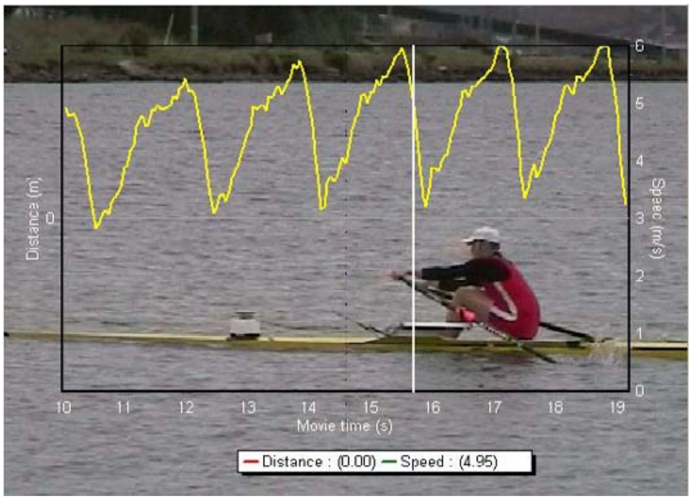

Figure 12: shows the oarsmen just after the catch at the start of the drive phase.

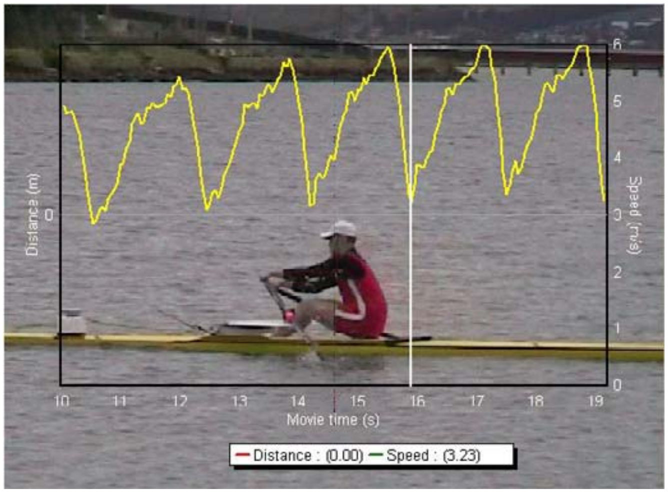

Figure 12: shows the oarsmen approximately 30 % through the drive phase.

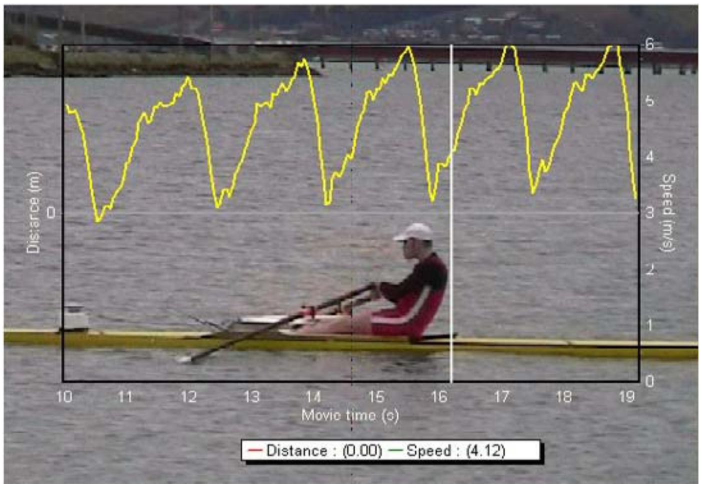

Figure 13: shows the oarsmen near the end of the drive phase, before the oarsmen extracts the blades from the water.

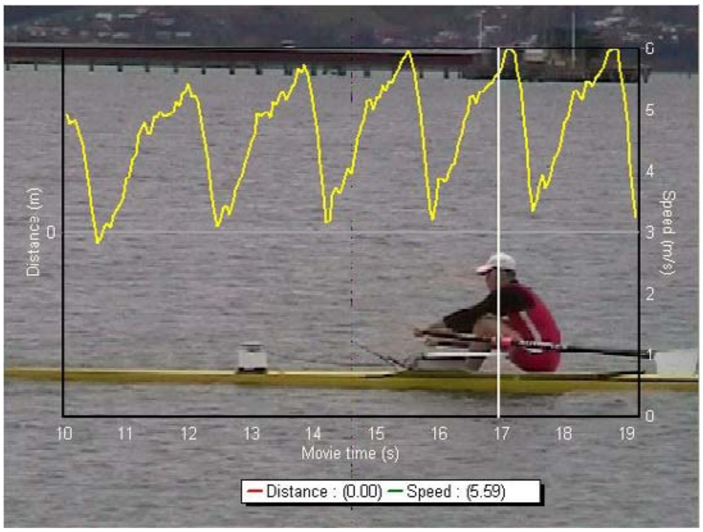

Figure 15: shows the rower ¾ through the recovery phase before the catch.

Conclusions & Recommendations

The preceding sections of the report have described the methods, the results and the possible errors associated with implementing the Leica 1200 GPS unit as a practical tool for assessing a racing skiff's dynamics. Several research strategies have been implemented and tested to demonstrate the usefulness of the GPS system for this purpose.

Key Findings

The overall task for this study is to answer the core question:

- "Can the velocity and acceleration of a rowing skiff be measured accurately using GPS to provide a viable coaching tool at race stoke rates (36 spm +)?"

The more specific objectives of the study are as follows:

- To evaluate the GPS procedures used and accuracies achieved to determine if the system could be developed as a viable tool for determining skiff velocity and acceleration.
- To quantify the effects that a GPS positioning error will have on the velocity and acceleration determination of the skiff.
- To access the viability of amalgamating the skiff's GPS derived velocity with video images for a coaching tool.

In order to achieve these objectives, **advanced measurement techniques** have been implemented. However, **standard** GPS hardware and software was used because of its "off the shelf" availability. Suitable measurement techniques had to be devised, tested and finessed because it was known that some of these dynamic changes are minute and happen quickly. This system has then been used to determine the velocity and acceleration changes of Otago University's light weight men's eight in training on Otago Harbour.

The three objectives (italicised) are listed below. Each is followed by a description of how the problem was addressed together with a summary of the results.

To determine the velocity and accelerations of an eight-oared skiff and single scull at race stroke rates and determine the precisions associated with the collected data sets.

The two rowing tests demonstrated the feasibility of GPS as a tool for measuring the velocity and acceleration changes of a rowing skiff. At 40 strokes per minute the equipment performed well on both the men's eight and a men's single. It was apparent from the graphs and the analysis that a 20 Hz update rate is needed to pick up the subtle dynamic responses at the high stroke rates. Thus, an RTK GPS measuring at 20 Hz has the ability to determine a skiff's velocity and acceleration at 40 strokes per minute. This is graphically shown in Figures 7, through to 10.

To quantify the effects that a GPS positioning error will have on the velocity and acceleration determination of the skiff.

The sensitivity analysis enables some of the "noise" seen in the graphs to be quantified (0.26 m/s) at the 20 Hz data-recording rate. This analysis suggests that unless the positioning precision of the GPS is improved, the "noise" will always be a negative characteristic when determining the skiff's velocity and acceleration.

To access the viability of amalgamating the skiff's GPS derived velocity with video images for a coaching tool.

The amalgamation of the GPS derived data with the video images proved to be a success and a lot simpler than anticipated with the help of siliconCOACH. A number of rowers and coaches have positively commented on the outcome and all believe that the combined system would prove to be an invaluable coaching aid. However, further development is needed to make the system a viable coaching tool. First, a decision needs to be made whether the system will operate in real time or as a post-training session coaching tool. Secondly, a better method of synchronisation between the GPS and the video needs to be implemented using the PPS output on the receiver. Thirdly, the equipment price will need to be assessed to make it more accessible to provincial and local level clubs although, by comparison, an eight-oared skiff costs about NZ $ 35,000.

Overall, this measurement system offers exciting prospects as a coaching aid in the sport of rowing and, possibly, also for other sports such as canoeing and cycling. The practical attraction of the current system comes from the ease at which this gear can be accessed and mounted on the skiff when compared to the cumbersome equipment and testing used in photogrammetric techniques. As a system it is sufficient for a coach or crew to analyse their performance on the local river or harbour, provided that there is clear and unimpeded access to the satellite signals. As an alternative to purchasing the equipment, it could be hired from a local survey firm for about $400 a day, which is a small price to pay for success, especially on the international scene!

Now, to address the original question!

"*Can the velocity and acceleration of a rowing skiff at race stroke rates be measured accurately using GPS to provide a viable coaching tool?*"

The short answer is Yes. GPS measuring at 20 Hz is a viable tool for measuring a skiff's velocity and acceleration at <u>40 strokes per minute</u> as has been shown in the preceding sections of this study.

Recommendations

This following section outlines some of the areas of advanced research that arise from this study. The recommendations for future research on this or similar topics are as follows:

- Evaluate the PPS output on the receiver for the best method of synchronising the GPS data with the video images. At present it would be best to set up a strobe light on the stern of the skiff to be controlled by the pulses from the PPS. To synchronise the two, the video operator would film the strobe light at the beginning of each test before filming the crew and skiff through the water.

- Assess the systems viability as a coaching tool. Is it best to have the system running in real time, or used as a post training tool? The disadvantage with a real time system is data management and data relay although siliconCOACH do currently utilise a technique that enables them to transmit real time video via a telemetry link to the rowers, who are wearing HMD's.[13] The advantage of a real time system would be that the athlete could see immediately what he or she is doing, both technically and quantitatively in terms of a velocity. In such circumstances, the athlete would be able to correct or complement their previous stroke immediately. Using a post processed system would only allow the athlete to correct their stroke in the next session.

- If the video system is chosen to be a real time coaching tool then it would be a good idea to test the possible errors that maybe associated with the system operating in an inverse RTK mode. Lambert and Santerre (2004) found that the inverse RTK system had a number of advantages, the main one being the reduced equipment weight. However, this is only applicable if the video system needs the positional data in real time. Inverse RTK is where the base acts as the rover, and the rover as the base, thus the base remains stationary on the bank. Because Lambert and Santerre (2004) also discovered that inverse RTK introduces further positional errors, these errors would need to be tested and evaluated on a rowing skiff.

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[13] **H**ead **M**ounted **D**isplays, these are glasses that display video images http://www.gadgets.co.uk/eye-top-eyetop-video-glasses-screen.html

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(A) Equipment List

The following list details the miscellaneous tools used in the study, for example the skiff and the rowers. Thirdly, the equipment used in the data analysis, including both hardware and software.

MISELLANOUS (The Skiffs and Rigging)

Men's Eight

- 2001, KIRS[14] 8+, manufactured in Cambridge, New Zealand.
    - 17.2 metres long.
    - 98 Kg.
    - Riggers (8, 6, 4, 2) were positioned on the stroke side and riggers (7, 5, 3, 1) were on the bow side.
    - All of the oarlocks were positioned so that the pitch of the blades ranged from 4 degrees at the perpendicular to 6 degrees at the catch.
    - The height of the oarlocks from 16 – 17 cm above the seats.
    - Crocker oars, with an overall length of 376 cm and an approximate weight of 800 g, were utilised. The inboard (force arm) measurement of the oar was 115 cm and the outboard the (resistance arm) measurement was 261 cm.
- The subject of the study was the Otago University representative light weight men's eight. The crew was tested on Otago harbour three weeks prior to racing at the Ilan International Regatta in Taiwan. The crew is coached by the Otago/Southland regional coach Juris Ezergailis.

Men's 1x

- 1998, Krutzmann 1 x, manufactured in Cambridge, New Zealand.
    - 8.4 metres long.
    - 15 Kg.
    - The span of the oarlocks 1598 mm.
    - All of the oarlocks were positioned so that the pitch of the blades ranged from 4 degrees at the perpendicular to 6 degrees at the catch.
    - The height of the oarlocks from 16 cm above the seats.
    - Crocker sculls, with an overall length of 291 cm and a combined weight of 800 g, were utilised. The inboard (force arm) measurement of the oar was 89 cm.
- The subject of the study was one of Otago Universities Senior Men. The sculler is coached by the Universities Senior Men's coach Nick Phillips.

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[14] **K**iwi **I**nternational **R**owing **S**kiffs

Appendix (B)

(B) GLOSSARY

This Appendix defines the technical terms and abbreviations used in this dissertation.

Blade:	The flattened or spoon-shaped Outboard end of a scull or sweep.
Bladework:	The action of the blade during a stroke.
Bow:	The forward section or nose of the skiff.
Bowside:	All the oarsmen whose oars are in the water on the starboard side of the skiff the (left side), when facing the stern.
Catch:	That part of the stroke when the oar is placed in the water; followed by the drive phase.
Check:	An abrupt change in the rate of deceleration caused by too much pressure on the stretcher without a simultaneous pressure on the pin (through the water). It is caused by too much pressure being applied to the footstretcher too quickly and is most evident in crews that rush toward the stern, then stop and catch before they start to drive. (Ferriss 1992)
Cockpit:	Space for the rowers in the skiff
Coxswain:	Steers the shell, usually from a seat in the stern, though in most modern pairs and some coxed IVs and VIII's the coxswain lies down in the bow to reduce air resistance and to spread the weight over more of the boat.
Crab:	Occurs when an oarsman finds it difficult or impossible to get the oar out of the water at the end of the drive phase. He may have gone too deep or become hung up on a wave or another's puddle (Edmond 1992).
Deck:	The covered areas of at the bow and stern of the skiff.
Drive:	The part of the stroke cycle between the catch and the release; also called the pull through.
Eight:	A sweep boat with eight rowers and a coxswain.
Feather:	To turn the blade over parallel with the surface of the water, this is done at the start of the recovery period. Feathering the blade is done to

lesson the wind resistance blade during the recovery.

Footstretcher: See Stretcher.

Gate: A bar across the oarlock to retain the oar.

Gunwale: The horizontal strips of wood running the length of the shell on both sides, to which the ribs, knees and skin are attached.

Handle: The part of the oar that is grasped by the oarsman.

Height: A rigging dimension measured from the lowest point of the seat to the middle of the bottom of the oarlock.

Inboard: On an oar, the distance from the end of the handle to the face of the button.

Lateral pitch: The angle of the pin away from the center of the shell. Also, outward pitch.

Layback: The amount of backward lean of the oarsman’s body (toward the bow) at the finish of the stroke.

Length in the water: The arc through which the oar moves during the drive. It will vary with the rower’s reach, the amount of slide used, the layback, the length of the oar and the ratio of inboard to outboard on the oar.

Leverage: Mechanical advantage resulting from the use of an oar.

Missing water: The fault of not anchoring the blade at full reach. Also known as missing the catch.

Oar (sweep): A leaver 3.76 metres long, weighing 800 grams, constructed of carbon fibre.

Oar (scull): A leaver 2.91 metres long, both weighing 800 grams, constructed of carbon fibre.

Oarlock (gate): A plastic ‘U’ shaped swivel that holds the oar in place. The oarlock rotates around a vertical pin.

Pitch: A rigging dimension the angle between blade Con the pull-through) or oarlock and a line perpendicular to the water’s surface.

Racing start: The first 20 to 40 strokes of a race, which are usually quicker than those used throughout the race. The first few strokes of the start are usually shorter in order to get the skiff moving.

Rating:	Rate of striking, or cadence; the number of strokes per minute that a crew is rowing at.
Recovery:	The part of the stroke cycle between the release and the catch in which the oar is made ready for the catch and the seat returned to the stern end of the slide.
Release:	The part of the stroke cycle when the oar is taken from the water and feathered.
Rhythm:	For any one crew, the proportion of time occupied on the recovery to the time taken on the pull-through; effective rhythm will help produce the best results for the power expended.
Run:	The run of a skiff is measured by the distance it travels in one stroke. In the water, run is shown by the distance between successive puddles from the same oar and is a good guide to the pace of the skiff. Favorable run is usually evident in an eight when the puddles clear the stern before the next stroke is taken.
Sculling:	Unlike sweep, sculling has two oars that are 2.9 metres long.
Single:	A sculling boat for one person.
Slide:	A seat that moves on wheels up and down two parallel runners 68cm to 81 cm long. There are stops at the front (stern) (denoted in rowing terminology as frontstops) and back (bow) (denoted backstops) of the tracks to prevent the seat from sliding off.
Spacing:	The distance between successive sets of puddles. Spacing varies with a crew's ability and especially with the rating. On a standard rigged 8 it is measured from two seat's puddle to stroke's catch. Spacing is a direct component of the skiffs run.
Speed training:	Exercises designed to improve the speed of a crew; always done in the interval form.
Spread:	The distance from the centerline of the skiff to the center of the pin. In sculling boats it is the distance between pins. Also known as span.
Standard rig:	Uniform alternation of riggers (and hence oars and rowers) in a skiff.
Starboard:	The right side of the boat as one faces the bow.
Stretcher:	The oarsman's feet are fixed on the stretcher, which consists of an inclined footrest with light shoes mounted on a frame attached at the top to the inside of the gunwale and at the bottom to the keel. Laces or straps hold the rowers feet in the shoes, which are fixed to the

	footstretcher plate. The whole stretcher is movable backward and forward and fixed with thumbscrews to allow oarsmen of different leg lengths to use as much slide as possible.
Stroke:	The rower nearest the stern who sets the rhythm and cadence for a crew. Also, the complete cycle of the rowing motion consisting of catch, drive, finish, and recovery.
Strokeside:	The side which has their oars extends out the port side of the skiff.